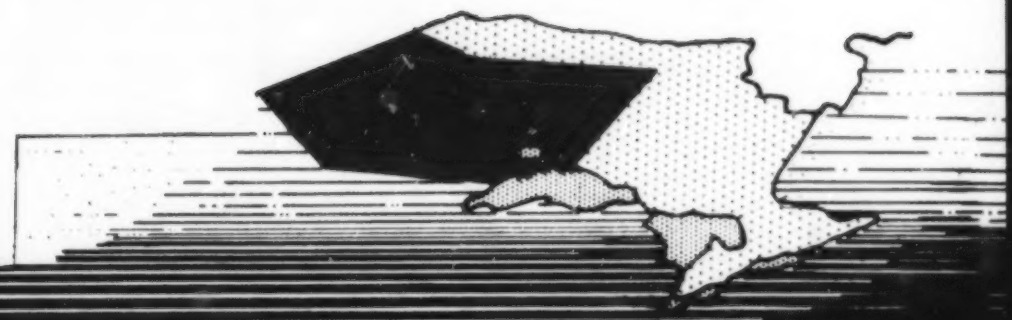

Ministry of Natural Resources
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NORTHWESTERN ONTARIO FOREST TECHNOLOGY DEVELOPMENT UNIT

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INFLUENCE OF INITIAL SPACING ON JACK PINE WOOD YIELD AND QUALITY

- A LITERATURE REVIEW -

by

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ABSTRACT

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Initial spacing of jack pine (Pinus banksiana Lamb.) is one of the most important factors influencing wood yield and wood quality. By regulating initial spacing the resource manager can influence mortality, diameter growth, trees and stand volume, rotation age, tree form and wood quality. Initial spacing has little or no effect on dominant height growth. Optimum spacing for jack pine is a function of product objectives (pulpwood, sawlogs) and should be considered in concert with site quality potential and economic analysis. For sawlog production, initial spacings of between 1.8 and 2.4 m are suggested in the literature. For the production of pulpwood, spacings of 1.8 to 2.2 m or greater should be considered.

KEYWORDS: Pinus banksiana, stand density, growth and yield.

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INTRODUCTION

Jack pine (Pinus banksiana Lamb.) is the most important commercial species in the Northwestern and North Central Regions of the Ontario Ministry of Natural Resources (O.M.N.R.). In the Northwestern Region, jack pine represents approximately 50% of the 2.9 million m^3 of wood harvested annually and 94% of the annual artificial regeneration program (Kennedy 1984). In the North Central Region, jack pine accounts for 31% of the 5.7 million m^3 of wood harvested annually and 40% of the annual regeneration program (Davison 1984). In both regions, over 70% of the jack pine harvest is used for pulpwood with the remainder used for sawlogs, ties and poles.

Artificial regeneration treatments for jack pine in northwestern Ontario consist of seeding (aerially or with site preparation), scarification for natural regeneration, and planting. Although direct seeding is the preferred method of artificial regeneration for jack pine, particularly in the Northwestern Region, the success of direct seeding can be variable (Kennedy 1984). Planting is often the surest and easiest way of establishing jack pine plantations, particularly on areas where there is an inadequate seed supply or where competing vegetation is expected (Davison 1984). An important benefit of planting is that it provides immediate control of stand density.

Regulation of stand density is one of the most effective methods for controlling the yield and quality of wood produced in plantations (Larson 1967). Planting too many stems per hectare will result in high establishment costs and long rotations due to reduced diameter growth. At the opposite extreme, too few trees will result in excessive branchiness and an undesirably high proportion of juvenile wood.

Recently, there has been a three-fold increase in the number of hectares being planted to jack pine in northwestern Ontario (Waito 1989, pers. com.).

Sparked by this rapid increase, questions have been raised regarding the influence of initial spacing regimes on the quantity and quality of wood produced from jack pine plantations. Diameter, form, total and merchantable volume, knot size and specific gravity will change as spacing is either increased or decreased, but by how much?

Historically, jack pine has been planted at 1.8 x 1.8 m spacing or 3,000 stems per hectare in northwestern Ontario. Unplantable spots such as rock outcrops and landings result in approximately 17% of the area within plantations not being plantable, resulting in 2,500 stems per hectare, planted at a 1.8 x 1.8 m spacing, becoming the actual standard planting density (Andison and Callaghan 1988).

Objectives of this paper are: 1) to review and summarize the current literature regarding the influence of initial density on jack pine yield and quality and 2) to provide the forest manager with a summary of initial spacings suggested in the literature for jack pine pulpwood and sawlog crops.

GROWTH AND YIELD EFFECTS

Published information pertaining to the influence of initial spacing on wood yield from jack pine plantations older than 30 years of age is relatively scarce. In contrast, publications describing growth and yield of jack pine plantations less than 30 years of age are available for many areas but relatively few exist for northwestern Ontario.

Initial spacing of jack pine affects mortality, average height, diameter, form, gross total volume and merchantable volume, but has little impact upon dominant height.

Mortality

The most common causes of mortality within the first four years after outplanting tend to be associated with either climatic factors, such as drought, or establishment factors, such as improper planting. In general, mortality tends to decrease with increased initial spacing. This trend may be explained to some degree by the fact that tree planters have a proportionately greater number of better microsites to choose from when planting trees at wider spacings.

Lower jack pine mortality at wider spacing has been documented by several authors (Ralston 1953, Bulger 1987). Ralston (1953) studied some effects of initial spacing (1.2, 1.8 and 2.4 m) on jack pine mortality on sandy outwash plains in northern Lower Michigan, 10 and 25 years after planting. Mortality rates for the first 10 years at 1.2, 1.8 and 2.4 m were 40, 36 and 34 percent; 15 years later they were 45, 40 and 39 percent, respectively (Maeglin 1967) (Table 1). From Nelder plot data, Bulger (1987) observed mortality rates of 33 and 26 percent for spacings of 1.22 and 2.46 m, respectively, after 19 years.

Table 1. Effect of initial spacing on the survival of jack pine plantations at 15 years of age.

Initial Spacing (m)	Planting Density (stems/ha)	Survival to 15 years of age (%)	Stand Density at 15 years of age (stems/ha)
1.23 x 1.23	6,610	72.8	4,812
1.85 x 1.85	2,922	86.8	2,536
2.46 x 2.46	1,652	95.6	1,579

Initial spacing will also influence the pattern of intraspecific competition (i.e., self thinning) as the stand of timber matures (Evert 1967) (Figure 1). Mortality from intraspecific competition is a function of growing space available to each tree, which is in turn dependent upon spatial distribution, density, and height of trees (Berry 1987). In general, no self thinning occurs until after crown closure has taken place and self thinning will begin earlier in close-spaced stands than in those more widely spaced (Berry 1984).

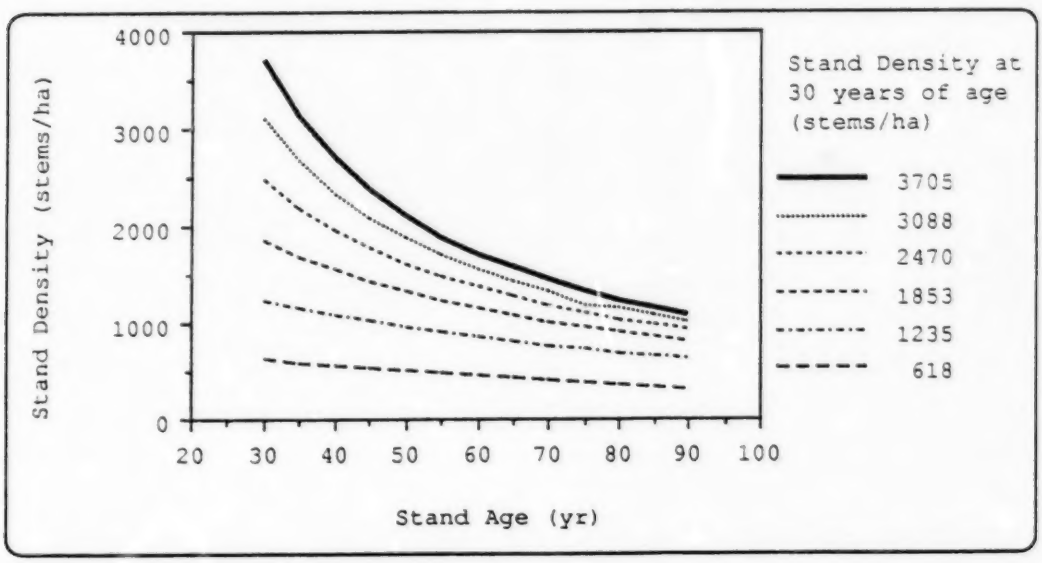

Figure 1. Influence of stand density on self thinning of natural jack pine stands from 30 to 90 years of age.

Height

Height growth of jack pine is not significantly influenced by initial spacing (Rudolf 1951, Guilkey and Westing 1956, Bulger 1987, Janas and Brand 1988) (Figure 2). However, lower heights have been reported in both very low and very high density stands (Chrozciewicz 1971). Janas and Brand (1988)

suggest that there may be height depressions exhibited at low densities caused by a lower degree of apical dominance, resulting in a higher proportion of photosynthate being allocated for diameter and crown development.

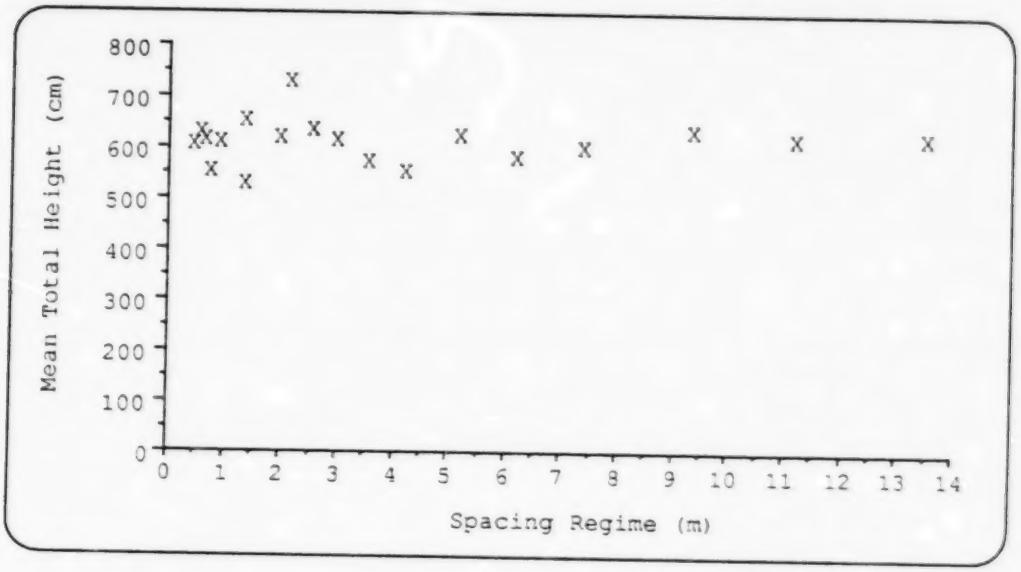

Figure 2. Influence of spacing on individual tree total height of jack pine at 19 years of age (Source: Bulger 1987).

Diameter

Minimum diameter values are critical for sawlog production. Stands with small average diameters produce a greater proportion of pulpwood and/or lower valued stud material than stands with higher average diameters (Gevorkiantz 1949). This relationship is illustrated in Figure 3 for red pine.

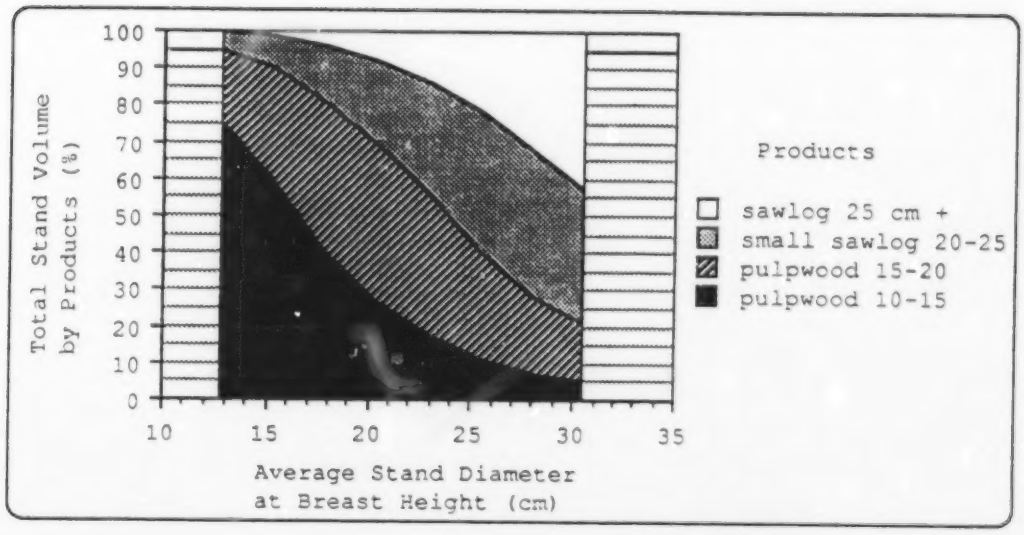

Figure 3. Proportion of various rough products in second-growth red pine stands.

Diameter growth of jack pine is positively correlated with site quality (Evert 1976) and negatively correlated with stand density (Evert 1976, Bella and De Franceschi 1980). Within natural stands, only small gains in diameter result if stand density is reduced from 3,700 to 1,800 stems/ha, but large gains in diameter size are realized if stand density is further reduced from 1,800 to 600 stems/ha (Evert 1976) (Figure 4).

Within plantations, jack pine displays a consistent increase in average diameter with increased spacing (Bolghari and Bertrand 1984, Bulger 1987, Janas and Brand 1988). Results to age 20 of a block spacing study show that average diameter increased from 10.7 cm at 1.2 m spacing to 14.8 cm at 2.4 m spacing with no further increases at 3.0 m spacing (Bella 1986).

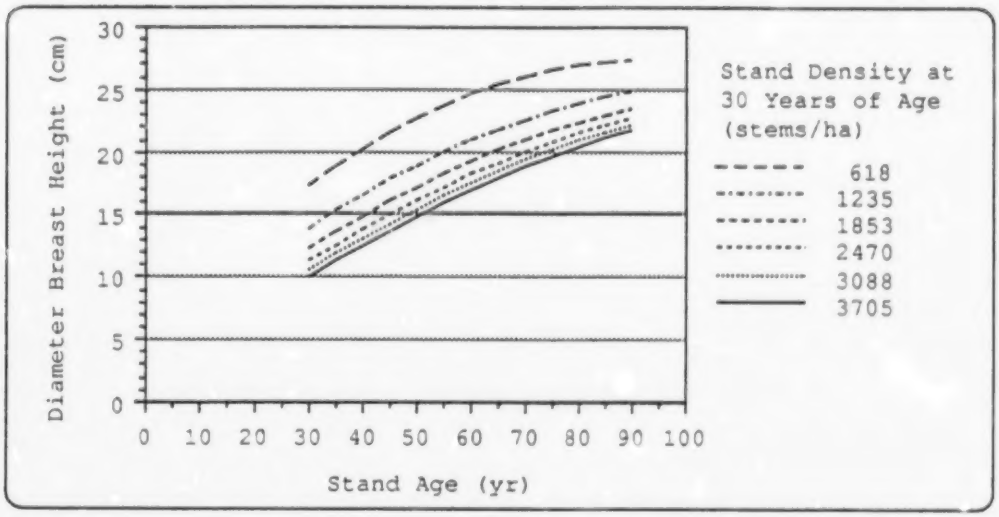

Figure 4. Influence of site and stand density on diameter growth of natural origin jack pine stands (site class 1).

In addition to average stem diameter, diameter distribution within a jack pine stand is also influenced by stand density (Ralston 1953, Maeglin 1967, Bella 1986, Janas and Brand 1988). At wider spacings, there is a higher percentage of trees in the larger diameter classes. Diameter distributions of three jack pine plantations studied by Ralston (1953) are presented in Table 2.

Table 2. Diameter class distribution of stems, expressed in percentage, of jack pine plantations at 25 years of age as affected by initial spacing.

Diameter Class (cm)	Percent Distribution at Spacings of		
	1.22x1.22 m	1.83x1.83 m	2.44x2.44 m
2.54-5.08	9	1	0
5.08-7.62	25	6	2
7.62-10.16	41	16	12
10.16-12.70	25	49	35
12.70-15.24	0	27	49
> 15.24	0	1	2
Total	100	100	100

Form

Initial spacing control can have a favourable effect on jack pine stem straightness. This is especially important for sawlog production, as crooked stems are difficult to mill and usually contain a greater proportion of compression wood.

Extremely high stand densities appear to be required if excellent tree form is to be achieved. From a study on jack pine sawlog quality comparing a high density natural origin stand (spacing of approximately 1.01 m) to plantations established at 2.13 and 4.27 m, Janas and Brand (1988) concluded that average stem quality of trees in the natural stand was better than either

of the two plantation stands at 21 years of age. There were no clear differences in form between the planted stands at the two spacing regimes.

Initial jack pine spacing has little influence on form during the initial establishment years (1-9 years after planting), but does affect it thereafter. From Nelder plot data, Bulger (1987) concluded that form, as measured by the mean absolute form quotient (M.A.F.Q.), was not significantly correlated with spacing ranging from 1.00 to 3.67 m at nine years of age. However, there was a significant correlation at 14 and 19 years of age. The M.A.F.Q. at 19 years of age is presented in Figure 5. The lower the mean absolute form quotient, the greater the taper (i.e., trees growing at 3.7 m spacing had more taper (0.48) than trees growing at 1.0 m spacing (0.63)).

The M.A.F.Q. is calculated as:

$$\text{M.A.F.Q.} = \frac{\text{diameter inside bark (cm) at 1/2 (total height (m) + 1.3 m)}}{\text{diameter breast height inside bark (cm)}}$$

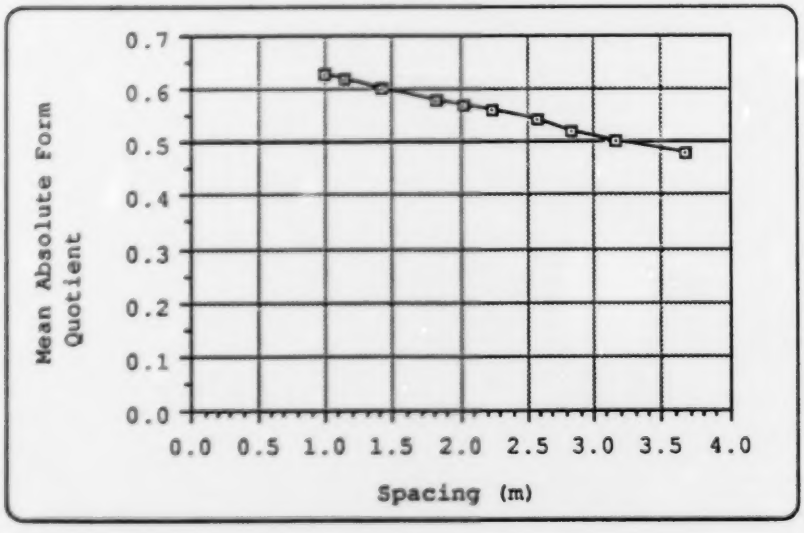

Figure 5. Mean absolute form quotient of jack pine as influenced by initial spacing.

Total and Merchantable Volume

Ideally, any selected spacing regime should be based upon desired final product and final total and merchantable yield on a per tree and/or per hectare basis. Practically, however, imperfect knowledge of the world at rotation age (50-80 years from now) means that today's decisions about initial spacings are based on presumed future product requirements. Within this overall context of uncertainty, however, some effects of spacing are well documented.

Total volume production of plantations decreases with increased initial spacing (Evert 1971). Difference in total volume production between spacings becomes less and less with increasing stand age (Evert 1971). In general, similar final yield can be achieved on a given site with a considerable range in initial stand densities. This occurs because a forest site has a fixed productive capacity i.e., there is only so much soil moisture, soil nutrients, carbon dioxide and sunlight available for plant growth. Just as there is a range of stand densities that will achieve the final constant yield for a given site, there is also a range of densities that are too low to achieve the final constant yield. One tree on a hectare will never produce as much wood fibre as a plantation of 1,000 stems per hectare.

Until reaching a physiological threshold, merchantable volume of natural jack pine stands increases with age, site quality and stand density (Evert 1976) illustrated Figure 6.

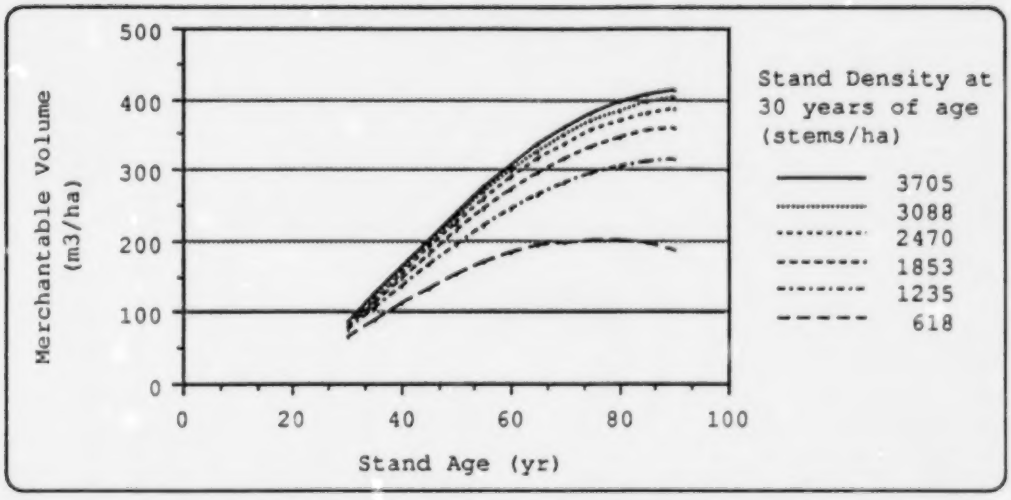

Figure 6. Influence of site quality and stand density on the merchantable volume of natural origin jack pine stands (Site Class 1).

Jack pine plantations have the potential to produce greater gross total and net merchantable volumes than natural stands on both a per hectare and per tree basis (Beckwith et al. 1984, Janas and Brand 1988). Beckwith et al. (1984) suggest that plantations may produce 10 to 15% more gross total volume than natural stands.

Jack pine individual tree volumes increase with wider spacing. Bella's (1986) data from a 20-year-old block spacing trial in Manitoba show that the greatest gross total volume per tree occurred at 2.4 m spacing, total volume per hectare at 1.2 m spacing and merchantable volume per hectare at 1.8 m spacing (Table 3). Thus, the spacing selected must be highly dependent upon the final desired product(s).

Table 3. Effect of tree spacing on tree and stand volumes of jack pine plantations at 20 years of age.

Spacing (m)	Tree Vol./tree Gross Total (dm^3/tree)	Volume per hectare Gross Total (m^3/ha)	Merchantable (m^3/ha)
1.2x1.2	19.6	131.7	42.0
1.8x1.8	35.4	106.1	69.0
2.4x2.4	48.1	81.0	61.4
3.0x3.0	41.6	44.8	34.2

LENGTH OF ROTATION

In general, if a biological rotation is defined as the point where current annual increment equals mean annual increment for gross total volume, shorter rotations can be achieved with high density stands. However, if the rotation is based on a minimum diameter limit, lower initial densities will result in faster individual tree diameter increments and shorter technical rotations. A list of technical rotation ages based on minimum diameter limits for natural jack pine stands at variable densities from Evert (1976) are presented in Table 4.

Table 4. Summary of technical rotation ages (years) based on minimum diameter limits for natural jack pine stands.

Site Class	Density at 30 yr. (stems/ha)	Minimum Diameter Limit (cm) 10	15	20	25
		Years			
1	618	<30	<30	35-40	60-65
	1853	<30	40-45	60-65	>90
	3088	25-30	45-50	70-75	>90
2	618	<30	<30	45-50	>90
	1853	<30	45-50	75-80	>90
	3088	30-35	55-60	85-90	>90
3	618	<30	40-45	65-70	>90
	1853	30-35	65-70	>90	>90
	3088	40-45	75-80	>90	>90

WOOD QUALITY

Control of spacing allows the resource manager to exert some degree of control over a number of wood quality factors including knot size, specific gravity, fibre length and extractive content. All of these factors are a function of crown development. The crown is both the source of photosynthate used for wood production and the regulating centre for wood production (Larson 1962).

Wood produced from fast-grown plantations will differ from wood produced in natural stands. Two of the most important of these differences will be knot size and the ratio of juvenile to mature wood. Whether the plantation wood is of lower quality to the wood from natural stands is dependent upon the final desired product.

Knot Size

Knot size is an important indicator of wood quality for the production of lumber. Strength properties and therefore value of the end product are inversely related to knot size.

Branch or knot sizes are largely controlled by the available space for crown development. Spacing affects knot size by influencing the length of time the live crown retains its lowest branches (Stiell 1964). Higher stand densities induce earlier crown closure and smaller branches (Wilde 1968) (Table 5).

Table 5. Effect of tree spacing on thickness of branches nearest to breast height and natural pruning of jack pine plantations at 17 years of age.

Spacing (m)	Tree Branch Diameter (cm)	Length of Live Crown (m)	Naturally Pruned Stem (% of total height)
0.62 x 0.62	0.80	2.92	60
1.23 x 1.23	1.28	3.69	56
1.85 x 1.85	1.60	4.92	44
2.46 x 2.46	2.08	5.38	27

Knot size can usually be minimized by close spacing but at the cost of reduced wood production on individual trees. An example of how stand density influences knot size is available form Ballard and Long (1988) for 80-year-old lodgepole pine (Figure 7).

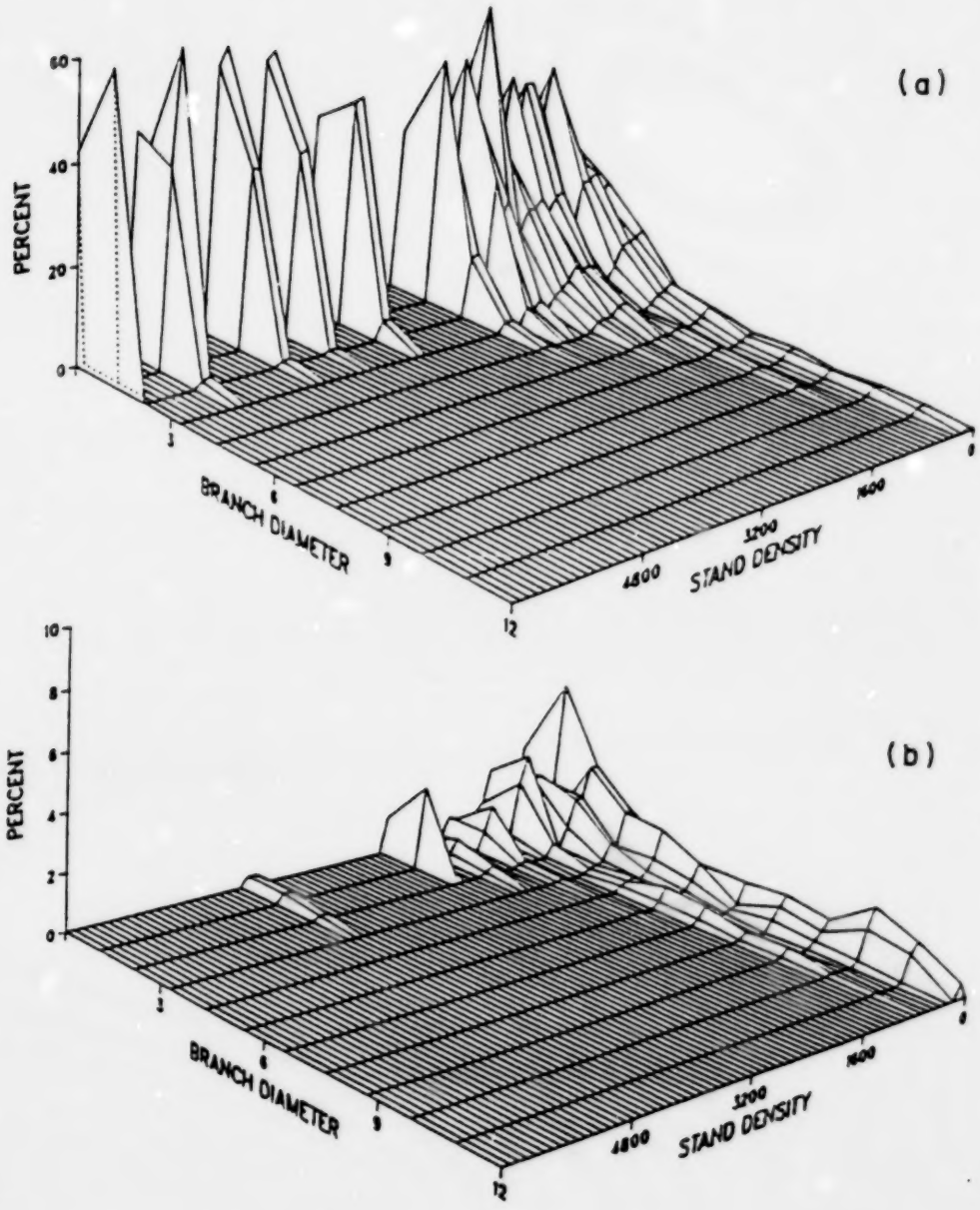

Figure 7. Relationship between number of branches (as percentage of total number of branches on the first log), branch diameter (cm) and stand density (stems per hectare) (a) all branches and (b) living branches.

Juvenile Wood Content

Juvenile wood is classified as that portion of the xylem surrounding the pith in a conical shape whose cells have not fully matured (Smith and Briggs 1986, Yang et al. 1986).

Juvenile wood has been a source of some concern, because it can constitute a considerable proportion of the total volume produced in short rotation plantations. Compared to mature wood, juvenile wood has many undesirable characteristics for paper and solid wood products, such as lower specific gravity, shorter tracheids and thinner cell walls (Bendtsen 1978, illustrated in Figure 8). Relative differences between paper and timber produced from juvenile and mature wood are presented in Table 6.

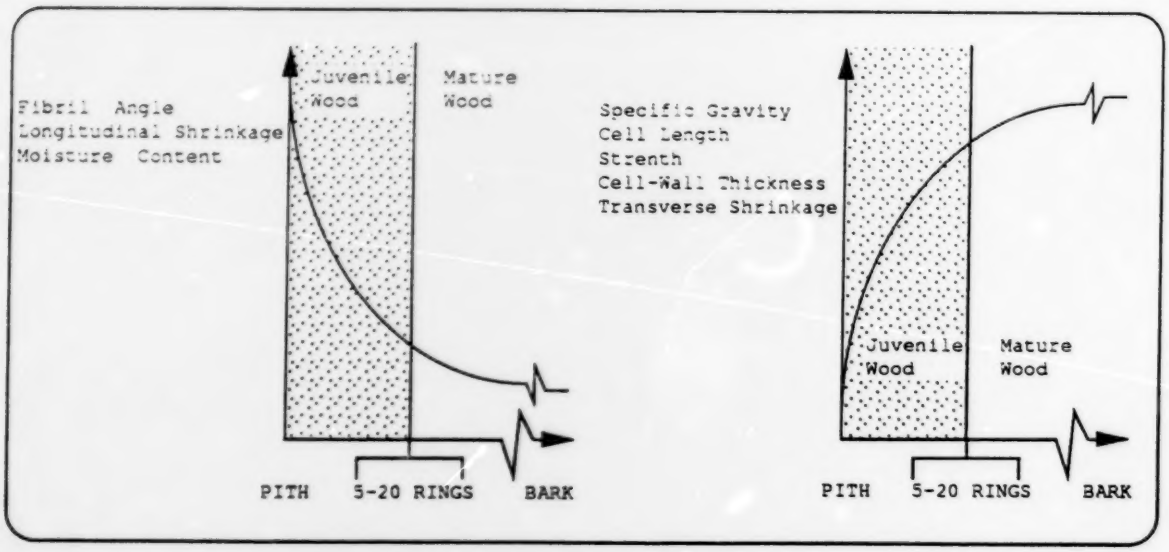

Figure 8. Schematic representation of the gradual change in properties from juvenile wood to mature wood in conifers.

Table 6. Relative differences in saw timber and paper properties between juvenile and mature wood.

Product	Property	Juvenile Wood	Mature Wood
Saw Timber	Longitudinal Shrinkage	Higher	Lower
	Transverse Shrinkage	Lower	Higher
	Strength	Lower	Higher
Pulp and Paper	Pulp Yield	Lower	Higher
	Tear Factor	Lower	Higher
	Burst Factor	Higher	Lower
	Tensile Strength	Higher	Lower

Juvenile wood is formed within and in proximity to the live crown. For this reason young trees with full crowns covering most of the bole produce juvenile wood almost exclusively for the first few years. As the base of the crown rises, the zone of juvenile wood also rises and remains within the general confines of the crown (Larson 1962). This results in a core of juvenile wood of approximately uniform diameter in the inner trunk of the tree (Larson 1967).

Although the demarcation between juvenile and mature wood is not clear because of the gradual change in properties, most researchers generally agree that the juvenile core includes anywhere from 5 to 20 rings, depending upon the species (Bendtsen 1978). For jack pine, the transition from juvenile to mature wood has been observed between 12 and 18 rings from the pith based on fibre length and growth rate data (Holmes 1988) and between 15 and 22 rings from the pith based on longitudinal shrinkage data (Keith 1986).

Absolute width of the juvenile zone (and to some extent the wood characteristics within the zone) can be modified by controlling stand density. Close spacing will confine the juvenile zone to a small central core, whereas

a wide spacing will expand the juvenile zone (Larson 1967). Close spacing can minimize the proportion of juvenile wood, but at the expense of slower diameter and volume growth of individual trees.

Specific Gravity

Specific gravity is considered to be the best single index of wood quality (Bendtsen 1978). There is a close relationship between wood density and both the strength of lumber and the yield of pulp (Baker 1967). Although small variations in specific gravity can cause large differences in the dry weight of fibre per cubic metre of wood, high specific gravity per tree does not necessarily result in high production of dry wood matter per hectare. In fact, the reverse is generally true (Wilde et al. 1951, Spurr and Hsiung 1954). Site conditions have also shown to exert a marked influence on the specific gravity of jack pine wood (Wilde et al. 1951). Jack pine growing on soils with relatively high productivity in terms of site quality, generally have lower specific gravities, but also produce the greatest quantity of wood by weight, on a per hectare basis. This was attributed to a higher volume of wood per hectare and higher volumes of solid wood per unit.

Specific gravity of wood is a function of a number of wood properties such as the proportions of earlywood and latewood fibres, the thickness of the fibre walls, and the chemical composition of the fibres, including extractives. The specific gravity of basic wood substance, (holocellulose and lignin) averages about 1.5 with little variation (Spurr and Hsiung 1954).

Specific gravity varies between and within trees. This variation has been attributed to differences in heredity, position within a tree, site, and stand history (Jayne 1958, Hall 1964, Keith 1986). In all cases, variation in

specific gravity is due to varying proportions of cell wall materials in the seasonal components of annual rings (Spurr and Husing 1954, Hall 1964).

Initial spacing has a small effect on specific gravity relative to site factors (Table 7). From a study of 15-year-old jack pine in Wisconsin, Maeglin (1967) concluded that specific gravity was not greatly affected by initial spacing. The slightly higher specific gravity recorded at the 2.46 m spacing was attributed to higher contents of both compression wood and extractives.

Table 7. Effect of tree spacing on specific gravity from increment cores taken from jack pine plantations at 15 years of age.

Tree Spacing (m)	Increment Core Specific Gravity	
	Mean	Range
0.62 x 0.62	0.333	0.290-0.368
1.23 x 1.23	0.334	0.296-0.382
1.85 x 1.85	0.333	0.290-0.372
2.46 x 2.46	0.349	0.305-0.398

Compression Wood

Compression wood is typically found on the lower side of leaning trees and on the underside of branches and is composed of relatively weak, rounded, thick-walled cells rich in lignin (Ladell et al. 1968).

The short, brittle tracheids found in compression wood are undesirable from both a pulpwood and sawlog perspective. Compression wood has low alpha cellulose yields, a high lignin content and consumes larger quantities of chemicals during pulping (Zobel 1981). Boards sawn from compression wood are weak and unstable,

with a greater amount of longitudinal shrinkage relative to boards sawn from mature wood (Zobel 1981).

The influence of spacing on the content of compression wood is not well documented. From a study of 15-year-old jack pine plantations spaced at 0.62, 1.23, 1.85 and 2.46 m, more compression wood was noted visually in increment core samples from the 2.46 m spacing than in other spacings (Maeglin 1967).

Extractives

Jack pine has an abundance of extractives which cause pulping problems when in the sulfite pulping process, and colour reversion in mechanical pulp (Redmond et al. 1971). In addition, wood preservation industries prefer wider sapwood (i.e., lower extractive content) in logs, because chemical treatment for wood preservation is then more effective (Yang et al. 1985).

Although information pertaining to the influence of initial spacing on extractive contents is lacking in the published literature, some inferences may be drawn. Studies have indicated that the width of sapwood generally increases with tree vigour, growth rate, tree diameter and crown size (Yang et al. 1985). Sinclair and Dymond (1973) determined that the amount of extractives in the heartwood increased rapidly when a tree reached an age of 45 years or around 20 cm in diameter. Since faster growth rates and shorter technical rotations are associated with wider spacings, lower extractive content should also be associated with wide spacings. Further work on the influence of spacing on jack pine extractive content appears warranted.

SPACING PATTERNS

Initial spacing is generally thought of in terms of square spacing, i.e., spacing in which the average distance between successive trees in a row is the same as the distance between rows and where plants in adjacent rows are opposite one another. This square pattern is often a result of existing site preparation configuration i.e., the spacing between rows is predetermined by the equipment. However, it may be desirable to consider rectangular spacing, in which the average distance between rows is either more or less than the distance between trees in a row.

Although published information is lacking pertaining to the effects of rectangular spacing on the performance of jack pine, information for European tree species is available. Low (1974) summarized this information and concluded: "it is reasonable to assume that rectangular spacing which does not depart radically from square spacing, e.g., 2.4 X 1.8 m instead of 2.1 x 2.1 m, will affect tree growth and timber properties in much the same way as the equivalent square spacing."

Rectangularity may indeed have some distinct advantages. Savings in site preparation, planting and weeding times can be realized by planting more trees within rows than between rows (Smith 1986). The wider the distance between rows, and the closer the trees within rows, the greater the rectangularity will be. Planning in advance to use a rectangularity ratio of 2:1 or more (between vs within row spacing) can reduce costs and avoid complications of subsequent commercial thinning and harvesting (Smith 1986).

SUMMARY OF JACK PINE SPACINGS RECOMMENDED IN THE LITERATURE

Desired spacing for jack pine is a function of product objective (eg., pulpwood, sawlogs) and must be examined in light of site quality potential and economic analysis. Based upon the literature (Table 8), spacings of jack pine between 1.8 and 2.4 m are suggested for sawlog production. For the production of pulpwood, spacings of 1.8 to 2.2 m or greater should be considered.

Table 8. Recommended initial spacings for jack pine.

Stand Age (yr)	Reference	Comments and Conclusions of Authors
10	Rudolf (1951)	At 10 years of age 1.64 m (3,706 stems/ha) looked like good stocking, 2.24 m (1,976 stems/ha) appeared to be the minimum acceptable stocking and 2.85 m (1,235 stems/ha) were too few for satisfactory development.
19	Bulger (1987)	Initial spacing between 1.8 m and 2.2 m appears acceptable for the production of sawlogs on sites of deep well drained, fine sands. For the production of pulpwood, spacings wider than 2.2 m may be advantageous if economic returns are sufficient and competition problems are not serious.
20	Bella (1986)	Suggests an optimal initial spacing between 1.8 m and 2.4 m for jack pine.
30-90	Evert (1976)	From a stand production point of view, 1,705 stems per hectare (approximately 2.4 m) might be a stand density worth aiming at on a poor site or 3,064 stems per hectare (approximately 1.8 m) on a good site.

SUMMARY AND CONCLUSIONS

Because of the shortage of direct information on the subject, caution is required in making conclusions from the spacings recommended in the literature. However, the following conclusions have been drawn in order to provide some guidance on the subject to forest managers. Initial spacing, and resulting stand density, of jack pine are important factors in terms of maximizing growth rate and site productivity. Initial spacing influences mortality, stand and tree diameter and volume, biological and technical rotation ages, tree form, crown length and width and wood quality. Initial spacings have little or no effect on height growth. Wider initial spacings reduce establishment costs, reduce technical rotation ages, offset thinning and avoid the harvest of small sized trees. Close initial spacings result in early crown closure, smaller knot size, lower ratio of juvenile to mature wood, higher specific gravity, better form, earlier site occupancy, faster accumulation of gross total volume and shorter biological rotation ages.

Desired spacing should be a function of product objectives (e.g., pulpwood, sawlogs) and the resources available (e.g., site and financial resources). Spacings of 1.8 to 2.4 m are suggested for jack pine sawlog crops, and spacings of 1.8 to 2.2 m or more are recommended for pulpwood crops.

FUTURE DIRECTION

To augment the existing literature, it is recommended that a number of jack pine spacing trials/demonstration areas be established to validate this information for Northwestern Ontario. In these trials, a primary aim would be to study the effects of initial spacing on crop establishment, early growth, and quantity and quality of wood produced.

LITERATURE CITED

Armson, K.A. 1978. Management of jack pine species. Pp. 2-1 to 2-20. in F.L.C. Reed and Associates. Forest Management in Canada. Vol. II. Case Studies. For. Manage. Institute, Inf. Rep. FMR-X-103.

Andison, D. and Callaghan, B.P. 1988. Survey of artificially regenerated sites North Central Region. Ont. Min. Nat. Resour., For. Mgmt. Br., Unpub. Rep.

Ballard, L.A. and Long, J.N. 1988. Influence of stand density on log quality of lodgepole pine. Can. J. For. Res. 18:911-916.

Baker, G. 1967. Estimating specific gravity of plantation grown red pine. For. Prod. J. 17(8):21-24.

Beckwith, A.F.; Roebbelen, P. and Pessione, S. 1984. Variable density growth and yield of managed jack pine plantations. Pp. 145-156. in Smith, C.R. and G. Brown (Co-Chairs). Jack pine Symposium. C.O.J.F.R.C. Symp. Proc. O-P-12.

Bella, I.E. 1986. Spacing effects 20 years after planting three conifers in Manitoba. Can. For. Serv., Northern Forest. Cen., For. Mgmt. Note No. 39. 11 pp.

Bella, I.E. and De Franceschi, J.P. 1980. Spacing effects 15 years after planting three conifers in Manitoba. Northern For. Res. Cen., Inf. Rep. NOR-X-223. 10 pp.

Bendtsen, B.A. 1978. Properties of wood from improved and intensively managed stands. For. Prod. J. 28(10):61-72.

Berry, A.B. 1984. Volume and biomass yield tables for unthinned red pine plantations at the Petawawa National Forestry Institute. Can. For. Serv., Inf. Rep. PI-X- 32. 27 p.

Berry, A.B. 1987. Plantation white spruce variable density volume and biomass yield tables to age 60 at the Petawawa National Forestry Institute. Can. For. Ser., Inf. Rep. PI-X-71. 21 p.

Bolghari, H.A. and Bertrand, V. 1984. Tables preliminaires de production des principales essences resineuses plantees dans la partie centrale du sud du Quebec (preliminary yield tables for the main coniferous spieces planted in central southern Quebec). Gouv. du Quebec, Min. de L'Energie et des Ress., Serv. de la Rech. (Ter. et For.). Memoire No. 79. 392 pp. (French with English abstract).

Bulger, W.D. 1987. Nelder spacing trials for jack pine: A sample analysis. Ont. Min. Nat. Resour., Kirkland Lake District, Int. Rep. 34 pp.

Chrosciewicz, Z. 1971. The growth response of young jack pine to moderate and extreme stand densities. Bi-mon. Res. Note 27(1).

Davison, R.W. 1984. Jack pine management in the boreal forest of Ontario: North Central Region. Pp. 169-172. in Smith, C.R. and G. Brown (Co-Chairs). Jack pine symposium. C.O.J.F.R.C. Symp. Proc. O-P-12.

Evert, F. 1971. Spacing studies- A review. Can. For. Serv., Dept. Environ., For. Manage. Inst., Info. Rep. FMR-X-37. 95 pp.

Evert, F. 1976. Management-oriented yield tables for jack pine cover type in northern Ontario. Dept. Environ., Int. Rep. FMR-X-87. 43 pp.

Gevorkiantz, S.R. 1949. Proportion of various rough products in second-growth stands. U.S.D.A., For. Serv., Lake States For. Exp. Stn., Tech. Bull. 308.

Guilkey, P.C. and Westing, A.H. 1956. Effects of initial spacing on the development of young jack pine in northern Lower Michigan. Mich. Acad. Sci. Arts, Letters, Pap. 41:45-50.

Hall, A.D. 1964. The relationship between rate of growth and specific gravity in black spruce. Ont. Dept. Lands and For., Res. Br., Sec. Rep. (For.) No. 50. 10 pp.

Holmes, B.D. 1988. Fiber length study of second growth jack pine (Pinus banksiana Lamb.) naturally regenerated. B.Sc.F. Thesis, Sch. For., Lakehead Univ., Thunder Bay, Ont. 70 pp.

Janas, P.S. and Brand, D.G. 1988. Comparative growth and development of planted and natural stands of jack pine. For. Chron. 64(4):320-328.

Jayne, B.A. 1958. Effect of site and spacing on the specific gravity of wood of plantation grown red pine. Tappi 41:162-166.

Keith, C.T. 1986. An exploratory study of the properties of fast grown jack pine and european larch in eastern Canada. Forintek Canada Corp. Unpubl. Rep. 88pp.

Kennedy, F.D. 1984. Jack pine regeneration in the Northwestern Region. Pp. 163-168. in Smith, C.R. and Brown, G. (Co-Chairs). Jack pine symposium. C.O.J.F.R.C. Symp. Proc. O-P-12.

Ladell, J.L.; Carmichael, A.J. and Thomas, G.H.S. 1968. Current work in Ontario on compression wood in black spruce in relation to pulp yield and quality. Pp. 52-60 in Proceedings of the Eighth Lake States Forest Tree Improvement Conference. Sept. 12-13, 1967. U.S.D.A., For. Serv., Res. Pap. NC-23.

Larson, P.R. 1962. A biological approach to wood quality. Tappi 45(6):443-448.

Larson, P.R. 1967. Silvicultural control of the characteristics of wood used for furnish. Tappi 50:143-151.

Low, A.J. 1974. Initial spacing in relation to establishment and early growth of conifer plantations. United Kingdom, Forest. Comm. Res. Dev. Pap. 110. 14 pp.

Maeglin, R.R. 1967. Effect of tree spacing on weight yields for red pine and jack pine. J. For. 65:647-650.

Ralston, R.A. 1953. Some effects of spacing on jack pine development in Lower Michigan after 25 years. Mich. Acad. Sci. Arts and Letters, Pap. 37, 137-143.

Redmond, W.A.; Coffey, B.B.; Shatri, S. and Manchester, D.F. 1971. Non-structural chromophoric substances in jack pine wood and pulps. Pulp Pap. Mag. Can. 72:85-92.

Rudolf, P.O. 1951. Stand density and the development of young jack pine. J. For. 49:254-255.

Sinclair, G.D. and Dymond, D.K. 1973. The distribution and composition of extractives in jack pine trees. Can. J. For. Res. 3:516-521.

Smith, J.H.G. 1986. Use of wide spacings to reduce costs and increase volumes and values grown. Can. For. Ind. B44-B52.

Smith, W.R. and Briggs, D.G. 1986. Juvenile wood: Has it come of age? Pp. 5-9 in Robertson, D. (Coordinator). A technical workshop: Juvenile wood- what does it mean to forest management and forest products? For. Prod. Res. Soc. Proc. 47309.

Spurr, S.H. and Hsiung, W. 1954. Growth rate and specific gravity in conifers. J. For. 52(3):191-200.

Stiell, W.M. 1964. Twenty-year growth of red pine planted at three spacings. Can. Dept. For., Publ. No. 1045. 24 pp.

Wilde, S.A. 1968. Tree spacing in forest plantations as related to soil and revenue. Res. Div., College of Agriculture and Life Sciences. Univ. Wisconsin. 22 pp.

Wilde, S.A.; Paul , B.H. and Mikola, P. 1951. Yield and quality of jack pine pulpwood produced on different types of sandy soils in Wisconsin. J. For. 49:878-881.

Yang, K.C.; Bensen, C.A. and Wong, J.K. 1986. Distribution of juvenile wood in two stems of Larix laricina. Can. J. For. Res. 16:1041-1049.

Yang, K.C.; Hazenberg, G.; Bradfield, G.E.; and Maze, J.R. 1985. Vertical variation of sapwood thickness in Pinus banksiana Lamb. and Larix laricina (Du Roi) L. Koch. Can. J. For. Res. 15:822-828.

Zobel, B.J. 1981. Wood quality from fast growing plantations. Tappi. 64(1):71-74.